JPL ACTIVATED CARBON TREATMENT SYSTEM (ACTS) FOR SEWAGE

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## ABSTRACT

Jet Propulsion Laboratory has developed an Activated Carbon Treatment System (ACTS) for sewage.* Application of ACTS has been developed jointly with the County Sanitation Districts of Orange County (CSDOC) and is being applied to a one-million gallon per day sewage treatment pilot plant under construction at CSDOC. Sponsorship is under the Environmental Protection Agency Step I Grant No. C-06-1073. JPL-ACTS development activities reported include pyrolysis and activation of carbon-sewage sludge, and activated carbon treatment of sewage to meet ocean discharge standards. ACTS Sewage treatment operations include carbon-sewage treatment, primary and secondary clarifiers, gravity (multi-media) filter, filter press dewatering, flash drying of carbon-sewage filter cake, and sludge pyrolysis and activation. Tests were conducted on a laboratory scale, 10,000 gallon per day demonstration plant and pilot test equipment. Preliminary economic studies are favorable to the JPL-ACTS process relative to activated sludge treatment for a 175,000,000 gallon per day sewage treatment plant.

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*This report presents the results of research and design development carried out at the Jet Propulsion Laboratory, California Institute of Technology, under contract NAS7-100, sponsored by the National Aeronautics and Space Administration, and the County Sanitation Districts of Orange County.

## GLOSSARY

| | |
|---|---|
| ACTS | Activated Carbon Treatment System |
| BOD | Biochemical Oxygen Demand |
| COD | Chemical Oxygen Demand |
| CSDOC | County Sanitation Districts of Orange County |
| EPA | Environmental Protection Agency |
| GPD | Gallons Per Day |
| I. D | Inside Diameter |
| MGD | Million Gallons per Day |
| O. D. | Outside Diameter |
| R. P. M. | Revolutions Per Minute |
| SS | Suspended Solids |

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## I. INTRODUCTION

Jet Propulsion Laboratory develope Activated Carbon Treatment System (ACTS) for sewage (ref. 1). Deve nt of the ACTS for treatment of municipal sewage has been carried out jointly with the County Sanitation Districts of Orange County (CSDOC). Initial ACTS development included laboratory test and research, 10,000 gallon per day demonstration plant, and pilot plant equipment tests. Development activities have led to undertaking the de r, and construction of a 1 million gallon per day (MGD) pilot plant at Orange County Sanitation District (OCSD) under Environmental Protection Agency Grant No. C-06-1073. Pilot Plant construction should be complete by February 1976. A Six-months plan of operation is projected for evaluation of the ACTS process to meet ocean discharge standards (ref. 2) and for economic evaluation.

Participating organizations in the 1 MGD ACTS Pilot Plant in addition to the Jet Propulsion Laboratory (JPL) and National Aeronautics and Space Administration (NASA) include the County Sanitation Districts of Orange County (CSDOC), California State Water Resources Control Board (SWRCB), Environmental Protection Agency (EPA) and John Carollo Engineers.

ACTS development including the design of the 1 MGD Pilot Plant and preliminary economic evaluation of ACTS relative to activated sludge sewage treatment for a 175 MGD sewage treatment plant are presented.

## II. JPL-ACTS SEWAGE TREATMENT PROCESS

The JPL-ACTS sewage treatment process is outlined, Figure 1. Conceptually, the process uses activated carbon to provide secondary treatment of the sewage stream. The settled carbon-sewage sludge from the secondary clarifier is added to degritted raw sewage for primary treatment. Settled carbon-sewage sludge from the primary is dewatered through a filter press to 35-40% solids and flash dried to 90% solids before entering a rotary calciner for pyrolysis and activation of the carbon-sewage solids to activated carbon and ash. Activated carbon is fed back to the secondary clarifier to complete the carbon recycle. A proportion of the carbon-ash is purged from the carbon

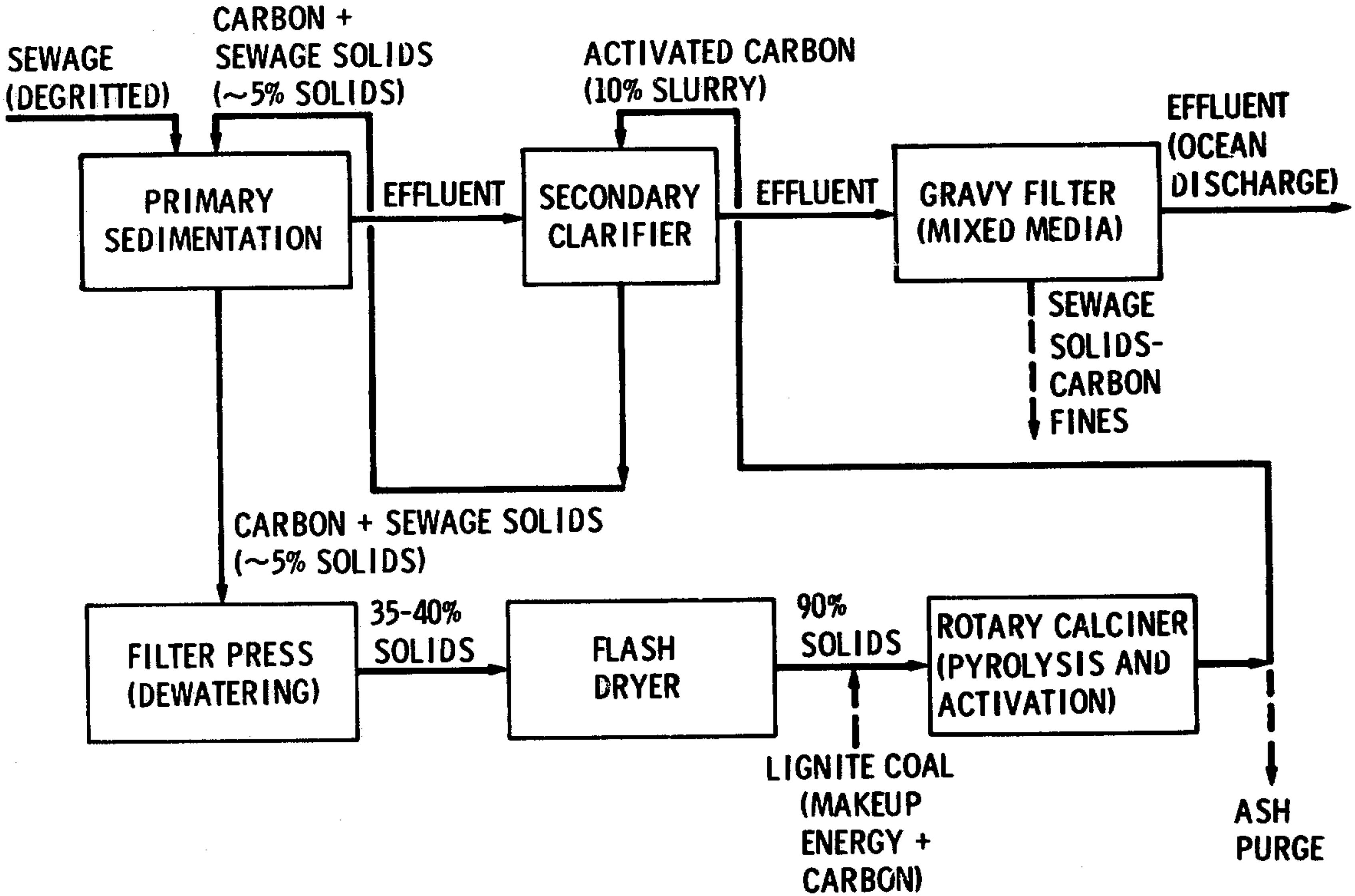


Figure 1. JPL-ACTS Process for OCSD

recycle to accommodate removal of the sand, clay, metals and other inorganic compounds present in the incoming sewage. The accompanying loss of activated carbon with the purge ash depends on the ash concentration established in the carbon recycle stream as well as on the level of ash (inorganic materials) in the incoming sewage. The energy value of the purged carbon can be recovered in a separate furnace by steam injection to make producer gas or by other means. Separation of ash and carbon derived from sewage processing by air or hydraulic classification including chemical assisted flotation has been unsuccessful to date (ref. 3). Acid washing at best removes 20% of the ash at considerable expense. Carbon losses with the ash purge constitute the largest single loss. Additional losses of carbon are found in the pyrolysis and activation of carbon. Conversion of sewage to activated carbon compensates to some extent for the losses. If low activation (Iodine Absorption < 400 mg/gram carbon) is acceptable for sewage treatment with a high ash content (>50%) in the recycle stream while maintaining a low carbon to sewage solids ratio (C/S < 1/1) and a low incoming ash (<20%), conversion of sewage to activated carbon could totally compensate for the carbon losses. Otherwise, activated carbon makeup is necessary from commercial sources, or by conversion of fuel or waste (refuse, etc.) additions to activated carbon. Commercial activated carbon is expensive and cannot be justified as makeup in significant amounts (>5-10%). Refuse when pyrolyzed and activated results in significant ash concentrations in the product carbon (>70%). Lignite coal provides a source of low ash carbon with activation comparable to commercial activated carbons and also provides at low cost the necessary makeup energy to the system for operation of the calciner and flash dryer.

Secondary effluent goes to a gravity, mixed-media filter before ocean discharge. The gravity filter will provide a final reduction of turbidity, suspended solids and BOD attendant to the carbon and sewage solid fines.

The inclusion of a flash dryer is extremely important to achieving high thermal efficiencies (~70%) for carbon-sewage sludge drying, pyrolysis and activation with an indirect-fired rotary calciner. Direct-fired furnaces such as rotary kilns and multiple-hearths provide high thermal efficiencies independent of a flash dryer but are subject to high powdered carbon losses in the stack gases as well as high carbon oxidation losses from air leaks and/or oxidation flames. Costs of the multiple-hearth units are expensive relative to

rotary calciners. Preliminary cost evaluation suggests a factor of 2 to 3 difference in installed equipment costs. Other cost factors such as equipment life and maintenance charges alter the impact of initial equipment cost differences on the overall process economics.

A photograph of the 10,000 gallon per day demonstration plant installed on two 30-foot long trailer beds and located at the CSDOC, Fountain Valley, California is shown, Figure 2. Equipment included: two 300-gallon carbon contactors and coagulators for primary and secondary carbon-sewage contact; two halves of a 1180 gallon rectangular tank serve as primary and secondary clarifiers; two 250-gallon tanks provide sludge concentration and filtrate storage; a 22 $ft^2$ plate and frame filter press and a 3-foot diameter x 1-foot rotary vacuum filter for solids dewatering; an 8-inch I. D. x 5-foot long externally gas fired fixed kiln for carbon-sewage pyrolysis and steam activation.

Plant layout of the JPL ACTS 1 MGD pilot plant at CSDOC is shown, Figure 3. Design parameters for the 1 MGD Pilot Plant are indicated, Table I.

The design is based on sewage solids loadings of degritted raw sewage at 250 mg/liter. Carbon treatment requirements are based on a carbon/sewage solids ratio of 1/1. Ash in the recirculated carbon is assumed to be 50%. The design has been made sufficiently flexible to accomodate substantial increases in sewage solids and carbon loading.

## III. PYROLYSIS AND ACTIVATION

### A. LABORATORY TESTS

#### 1. Equipment and Procedure

Laboratory pyrolysis and activation of sewage, carbon-sewage and lignite coal for the production of activated carbon in the ACTS process was carried out in a one-inch O. D. quartz tube in an electrically-heated muffle furnace, Figure 4. The unit was equipped for controlled steam injection conditioned to the reactor temperature and a nitrogen sweep. Product gases were discharged to a series of two cold traps. Temperatures were controlled to contain oils and tars in the first trap and water in the second trap. The gases were then discharged to a gas holder that operated by the gas displacement of water. A thermocouple in the solids charge, 10 to 15 grams, monitored the reaction temperature. The solids were first inserted into the quartz tube, which was then placed in the hot muffle furnace preheated to the reaction

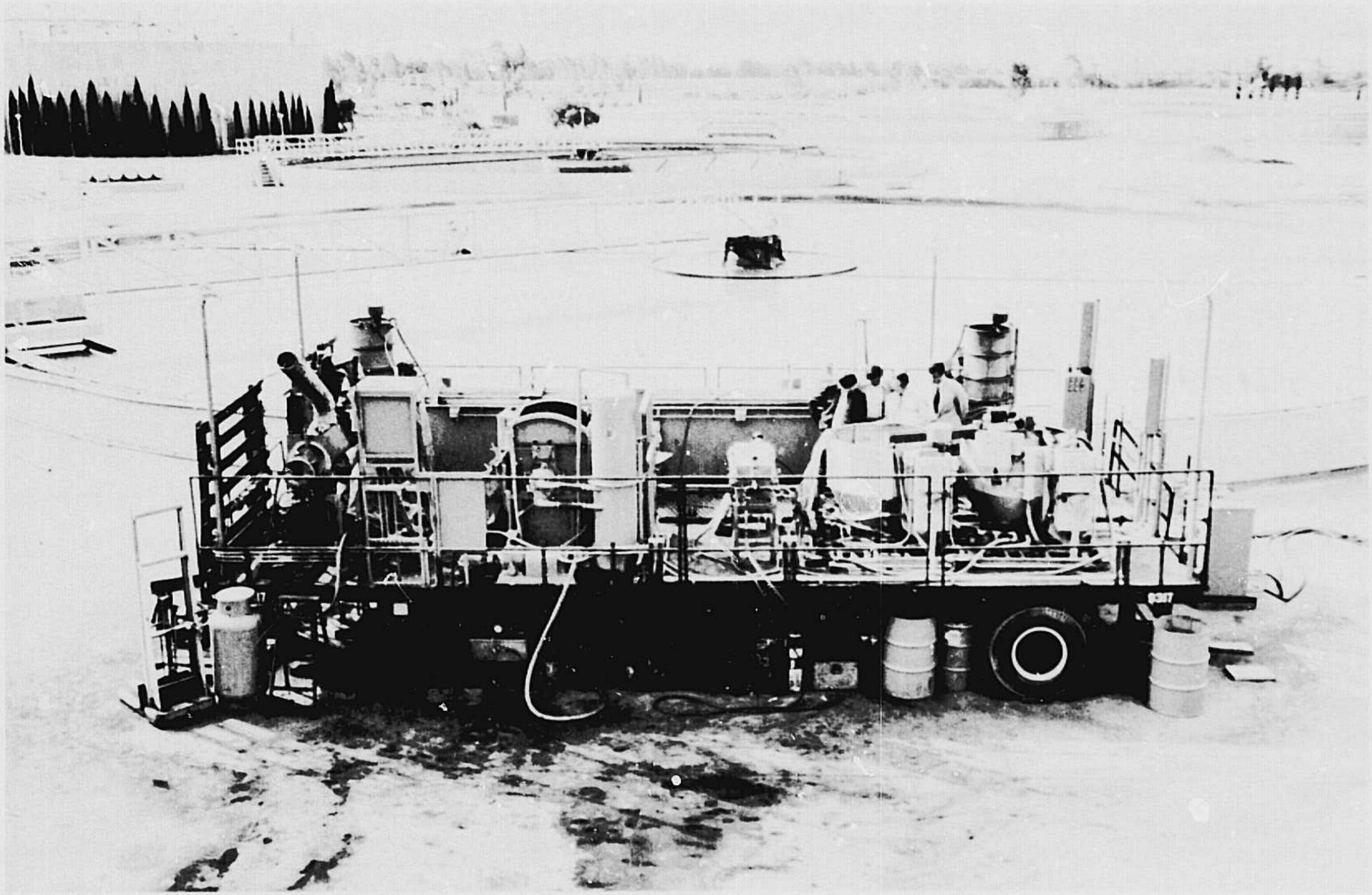

Figure 2. JPL-ACTS Sewage Treatment, 10,000 GPD Demonstration Plant at OCSD

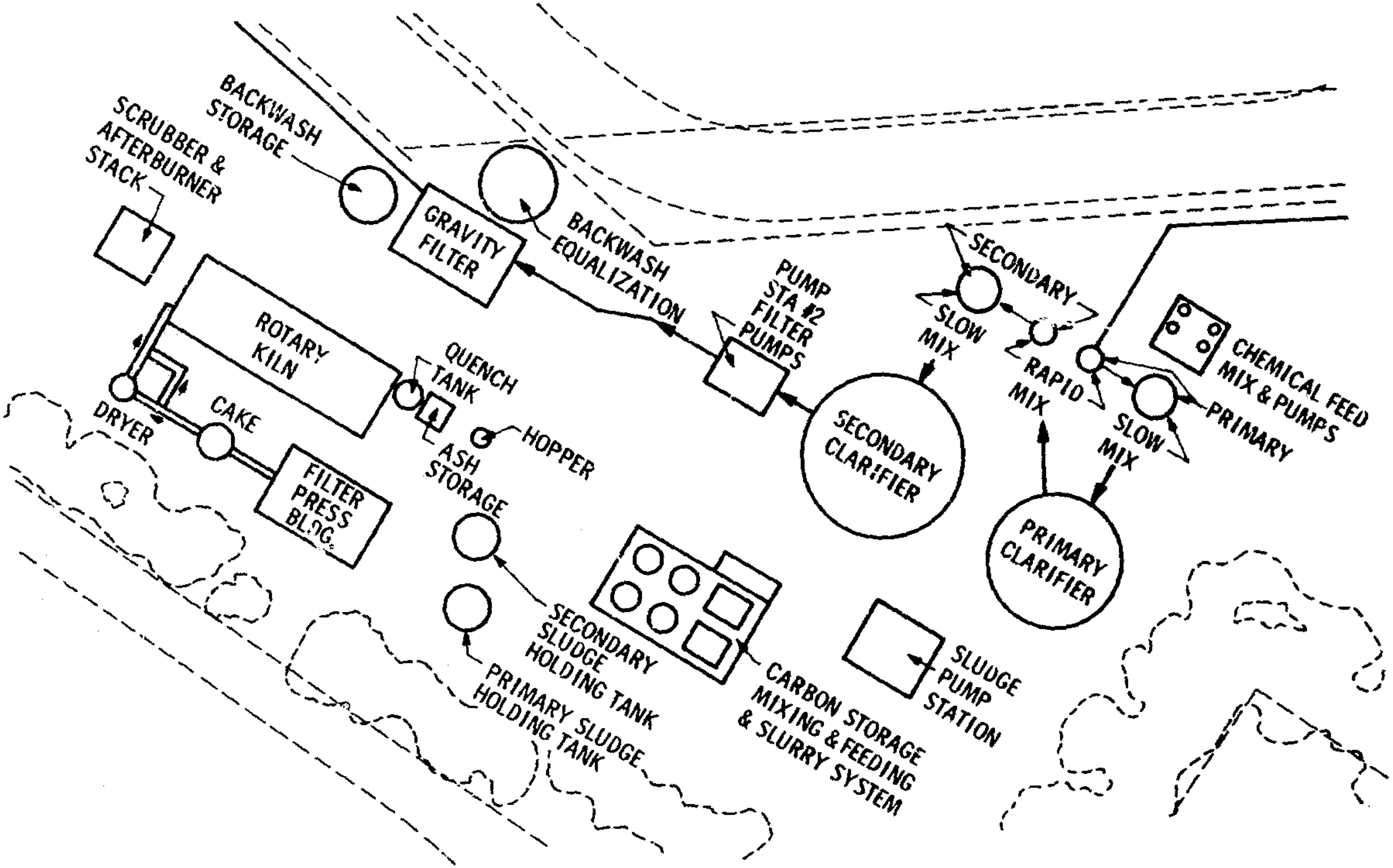


Figure 3. JPL-ACTS Process 1 MGD Pilot Plant Layout

Table 1. 1 MGD Acts Pilot Plant Design Parameters

| | |
|---|---|
| RAW SEWAGE (DEGRITTED) | 1 MGD (0.5 - 1.25 MGD) |
| SLUDGE HANDLING | |
| DRY SOLIDS (CARBON/ SEWAGE @ 1/1, ASH @ 50% IN RECIRCULATED CARBON) | 6400 lbs/ day |
| WET SOLIDS @ 6% SOLIDS | 107,000 lbs/ day |
| DEWATERED SOLIDS @ 33.3% SOLIDS | 19,200 lbs/ day |
| RAPID MIX TANKS (CARBON/ SEWAGE) | 2.5 minutes |
| PRIMARY AND SECONDARY | |
| SLOW MIX TANKS (CARBON/ SEWAGE) | 15 minutes |
| PRIMARY AND SECONDARY | |
| CLARIFIERS | |
| PRIMARY | 800 gpd/ $ft^2$ |
| SECONDARY | 600 gpd/ $ft^2$ |
| GRAVITY FILTRATION (3 units) | 2.5 - 7.5 gpm/ $ft^2$ |

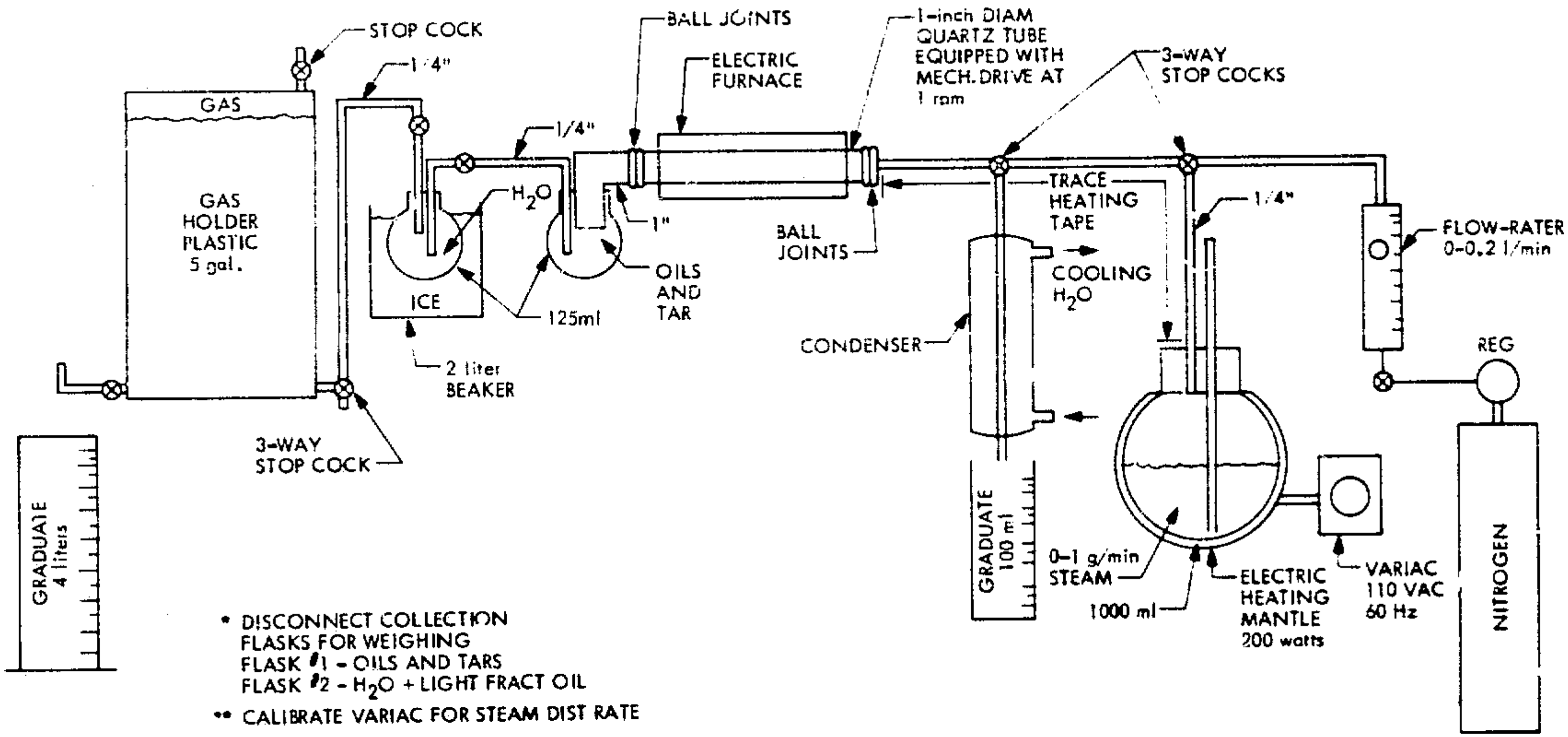


Figure 4. Laboratory Carbon-Sewage Pyrolysis and Activation Apparatus

temperature. Precautions were taken to provide a nitrogen blanket before insertion of the quartz tube into the hot zone. Early tests were made with tube rotation accomplished manually on an intermittent basis. The majority of tests were carried out with a mechanical drive continuously rotating the quartz tube at 1 R.P.M. Increased activation was noted with continuous rotation. Pyrolysis times reflect the measured time from quartz tube placement in the hot muffle furnace and until gas evolution ceased. Very evidently, heat transfer to the solids was limiting the pyrolysis. With good heat transfer, the pyrolysis would be complete in seconds and not minutes. Activation times were measured from the start of steam injection at the activation temperature until the termination of steam injection. Efforts were made to maintain an inert nitrogen blanket on the pyrolysis-activation product until the quartz tube had substantially cooled to near ambient temperatures.

Material balances were obtained by weighing the quartz tube with the solids before and after pyrolysis and activation. Traps on the discharge gases were weighed and a volume measurement obtained on the gas holder for pyrolysis gas evolution. Steam and nitrogen injection rates were monitored.

Sewage and carbon-sewage samples for pyrolysis-activation were first dried at 105°C. Analysis of representative samples were made for ash, fixed carbon and volatile matter. Gas analyses of discharge gases were made on representative samples by gas chromatography.

2. Test Data OCSD Sewage Pyrolysis

Laboratory data on pyrolysis of OCSD Sewage is presented, Table 2. Pyrolysis temperatures were from 560°C to 1100°C with corresponding pyrolysis times from 10-15 minutes to 2 minutes. The char remaining after pyrolysis was 38 to 46% of the original dry weight of sewage. The char consisted of 64 to 79% ash with the remainder being primarily fixed carbon. The yield of carbon based on the weight of dry sewage was between 8 and 16%. The yields of char and carbon were highest at the lowest pyrolysis temperatures and consistently decreased with increasing pyrolysis temperatures. Pyrolysis gases increased from 1065 $cm^3$ at 560°C to 2360-2890 $cm^3$ at 1100°C for a 10 gram dry sewage charge. This amount of pyrolysis gases accounts for approximately 25 to 50% of the volatile matter in the sewage samples. The remainder of the volatile

Table 2. Laboratory Pyrolysis of OCSD Sewage (1-inch Diameter Quartz Tube, Muffle Furnace)

| TESTS [2] | PYROLYSIS TEMP (°C) | PYROLYSIS [3] TIME (min.) | CHAR YIELD (%) | CHAR ASH [1] (wt %) | CARBON YIELD (%) | PYROLYSIS GASES ($cm^3$) [4] |
|---|---|---|---|---|---|---|
| (2-6) 12/13/74 | 560 | 7.5-10 | 43-46 | 65-70 | 13-16 | 1065 |
| (1) 12/13-18/74 | 620-630 | 6.5-10 | 41-46 | 68-73 | 11-14 | 1060-1100 |
| (2-3) 12/20/74 | 650 | 10 | 43-46 | 64-69 | 13-16 | 1735-1855 |
| (1-4) 12/20/74 | 660-730 | 8 | 41 | 72 | 11 | 1460 |
| (1-3) 12/5-9/74 | 820-870 | 9-15 | 39 | 77 | 9 | 1870 |
| (1-5) 12/5-9/74 | 900-920 | 7-15 | 40-42 | 71-75 | 10-12 | 1550-1850 |
| (3-4) 12/5/74 | 938-942 | 10-15 | 39 | 77 | 9 | — |
| (1) 12/18-19/74 | 1100 | 2 | 38-40 | 75-79 | 8-10 | 2360-2890 |

1 - OCSD SEWAGE ASH, 30 wt %
2 - 10-15 grams DRIED SEWAGE CHARGE IN QUARTZ TUBE
3 - TIME FOR GAS EVOLUTION TO STOP
4 - 70 F, 1 ATM.

matter given off is accounted for by oils and tars, water formation (combined oxygen in the sewage) and water soluble gases dissolved in the water displaced from the gas holder. Carbon yields based on the organic fraction of the sewage (correction for ash) are from 12.8 to 23%. The reduced yields of carbon at the higher pyrolysis temperatures probably represent some reaction of the fixed carbon with oxygen contained in the sewage for a reduced carbon yield. The larger amounts of pyrolysis gases at the higher pyrolysis temperatures reflect this occurrence as well as the increased cracking of oils and tars that are present with the laboratory-scale apparatus. In pilot test equipment, very little oil or tar formation was noticed, indicating that oils and tars were cracked by longer time exposure to the elevated temperatures.

3. Test Data ACTS Carbon-Sewage Pyrolysis

Laboratory pyrolysis was conducted on carbon-sewage samples obtained from the 10,000 gal/day ACTS demonstration plant located at OCSD, Table 3. The carbon was Darco G-60 with a carbon/sewage ratio of 1.0 to 1.4. Pyrolysis temperatures were 600 to 1000°C and pyrolysis times were 5 to 16 minutes. Char yields were from 70 to 78% with a corresponding yield of carbon based on the activated carbon of 100 to 120%. Lower temperatures resulted in the higher carbon yields. Pyrolysis gases were 600-670 $cm^3$ at 600°C to 1583-1930 $cm^3$ at temperatures of 925-1000°C for a 10 gram carbon-sewage charge. The highest carbon yield when based on the activated carbon present (% yield = (carbon out/carbon in) x 100) is obtained at the lowest carbon to sewage ratio. This is evident since the reduced carbon to sewage ratio reduces the possibilities of carbon losses and maximizes the carbon formation from sewage. This type of yield calculation can be misleading in that higher yields of carbon are forecast (as a percent of activated carbon originally present) by reducing the carbon/sewage ratio, although the absolute yield of carbon from sewage remains invariant.

4. Test Data-Activation

OCSD sewage and carbon-sewage samples obtained from the JPL-ACTS 10,000 GPD demonstration plant were pyrolyzed and steam activated, Table 4. Temperatures for pyrolysis and/or activation were from 560°C to 1000°C. Steam activation temperatures were in the range of 750 to 850°C, in this series

Table 3. Laboratory Pyrolysis of Carbon-Sewage from 10,000 GPD JPL ACTS Demonstration Plant at OCSD (1-inch Diameter Quartz Tube, Muffle Furnace)

| TEST | PYROLYSIS TEMP (°C) | PYROLYSIS TIME (min.) | CHAR YIELD (%) | CHAR ASH (wt %) | CARBON[4] YIELD (%) | PYROLYSIS GASES ($cm^3$) |
|---|---|---|---|---|---|---|
| (6-7) 1/7/75[1] | 600 | 7 | 72-75 | | 104-109 | 600-670 |
| (8-10) 1/7/75[1] | 700 | 7-9 | 71-74 | | 102-107 | 860-907 |
| (3-5) 1/7/75[1] | 740-780 | 7.5-9.5 | 70-71 | | 100-102 | [illegible]55-1110 |
| (1) 12/10/74[2] | 830 | 9 | 77 | | 120 | — |
| (1-3) 12/30/74[3] | 840 | 10-11 | 76-78 | | 106-110 | — |
| (1-2) 1/7/75[1] | 880 | 7.5-8.5 | 70-71 | | 100-102 | 1152-1275 |
| (3-6) 12/10/74[2] | 900-920 | 8.5-16 | 70-75 | | 114-120 | 990-1345 |
| (11-14) 1/7/75[1] | 925-1000 | 5-8 | 70 | | 100 | 1583-1930 |

1-CHARGE 10 grams OF DARCO G-60/ SEWAGE SOLIDS = 1.22/1 (OCSD 1/6/75)
2-CHARGE 10 grams OF DARCO G-60/ SEWAGE SOLIDS = 1/1
3-DARCO G-60/ SEWAGE $\simeq$ 1.4/1
4-% YIELD = (CARBON OUT/ CARBON IN) x 100

Table 4. Laboratory Pyrolysis and Activation of OCSD Sewage and Carbon-Sewage (1-inch Diameter Quartz Tube, Muffle Furnace)

| TESTS | STEAM ACT. (g/min) | ACTIVATION (PYROLYSIS) TEMP (°C) | ACTIVATION (PYROLYSIS) TIME (min) | ACTIVATION MATERIAL | CHAR ASH (wt %) | CARBON YIELD (%) | IODINE ABS. (mg/g CARBON) |
|---|---|---|---|---|---|---|---|
| | | | | **SEWAGE PYROLYSIS AND ACTIVATION** | | | |
| 1 | 0 | (560) | (10) | SEWAGE | 68 | 15 | 520 |
| 3 | 0 | (900) | (10) | SEWAGE | 75 | 11 | 655 |
| | 0.2 | 750 | 20 | SEWAGE | 80 | 7.8 | 670 |
| | 0.2 | 800 | 20 | SEWAGE | 82-85 | 6-7.4 | 778-1133 |
| | 0.2 | 850 | 10 | SEWAGE | 84 | 6 | 969 |
| | 0.2 | 850 | 15 | SEWAGE | 85 | 5.4 | 1013 |
| 4 | 0.2 | 850 | 20 | SEWAGE | 85-87 | 4.9-5.8 | 862-1120 |
| | | | | **CARBON-SEWAGE PYROLYSIS AND ACTIVATION** | | | |
| 9 | 0 | (700) | (7) | DARCO G-60/ SEWAGE - 1.2/1 *1 | | 16 | 440 |
| 11 | 0 | (880) | (8) | SEWAGE - 1.2/1 | | 12 | 480 |
| 13 | 0 | (1000) | 7 | SEWAGE - 1.2/1 | | 12 | 420 |
| 14 | 0.2* | 710 | 7 | SEWAGE - 1.2/1 | | 8 | 521 |
| 15 | 0.2* | 800 | 8 | SEWAGE - 1.2/1 | | 6 | 591 |
| 16 | 0.2* | 850 | 7 | SEWAGE - 1.2/1 | | -12 | 695 |

* 1-10,000 GPD DEMONSTRATION PLANT OCSD, 10 gram CHARGE *1

of tests. Steam rates were relatively low at 0.2 gram/min for a 10 gram charge. Later tests were at steam rates of 0.66 grams/minute with a 10 gram charge.

a. Sewage Carbon Activation

Salient results were that sewage undergoing pyrolysis with no steam activation showed high carbon activation based on iodine absorption tests. Activities were 520-655 mg/gram of carbon for iodine absorption. For comparison, Darco G-60 activated carbon has an iodine absorption value of 460 mg/gram.

b. Carbon-Sewage Activation

Corresponding activities for carbon-sewage pyrolyzed were substantially lower at iodine absorption of 420-480 mg/gram. Steam activation for 10-20 minutes following pyrolysis increased sewage carbon activity to 670-1133 mg/gram. Sewage-carbon activation for steam activation times of 7-8 minutes provided substantially lower iodine absorption, i.e., 521-695. Higher activation generally coincided with reduced carbon yields.

c. Carbon Recycle Activation

Laboratory tests were conducted using 20 liters of sewage treated with Aqua Nuchar to simulate the ACTS process in the laboratory. The resulting carbon-sewage sludge was filtered, dried and pyrolyzed-activated in a one-inch quartz tube. The carbon was recycled through the ACTS sewage treatment process and the results of carbon yield, ash content and activity monitored. The laboratory data are indicated, Table 5. Ash buildup in the carbon is rapid with the number of carbon recycles, increasing from 3 wt % to 33-44 wt % by cycle 3 and to 66 wt % by cycle 8. The ash contribution is from the sewage pyrolyzed-along with the carbon. Losses per cycle of carbon treatment appear relatively high, 9 to 27%. The losses represent not only activation losses but losses in the filtrate. Aqua Nuchar contains particle sizes down to minus 700 mesh. Therefore, substantial losses of carbon can be easily explained in the effuent. This data points up the need to minimize the use of powdered carbon of extremely large mesh size (above 325) because of difficulties attendant to obtaining good carbon settling. Activation of carbon on recycle through the ACTS process does not appear to be a problem. Based on activation conditions chosen,

Table 5. Carbon Sewage Pyrolysis and Activation, Laboratory Carbon Recycle Tests

| TESTS | STEAM ACT. (g/min) | ACT. TEMP. (°C) | ACT. TIME (min) | ACT. MATERIAL | CHAR ASH (wt.%) | CARBON YIELD[4] (%) | IODINE AbS. (mg/g CARBONS) |
|---|---|---|---|---|---|---|---|
| CYCLE 1 | 0.59 | 800 | 20 | AQUA NUCHAR[3] & SEWAGE SOLIDS[1] | | -27.2 | 840 |
| " 2 | " | " | " | " | | -9.3 | 1040 |
| " 3 | " | " | " | " | | -23.0 | 753 |
| CYCLE 3 | 0.66 | 750 | 10 | DARCO S-51[2] & SEWAGE SOLIDS | 33 | --- | 261 |
| " " | 0.2 | 850 | 15 | " | 33 | --- | 212 |
| " " | 0.66 | " | " | " | 35 | --- | 648 |
| " 8 | " | 850 | " | " | 66 | --- | 653 |
| CYCLE 1 | 0.66 | 850 | 20 | " | 26.5 | -17 | 752 |
| " 2 | " | " | " | " | 32.9 | -14 | --- |
| " 3 | " | " | " | " | 44.0 | -16 | 750 |

[1]TWO TREATMENTS OF OCSD SEWAGE AT 500 mg/ℓ

[2]DARCO S-51 ASH = 17.5 wt.%, IODINE AbS. = 648 mg/g

[3]AQUA NUCHAR ASH = 3 wt.%, IODINE AbS. = 850 mg/g

[4]YIELD LOSSES INCLUDE HYDRAULIC LOSSES IN TREATMENT ON RECYCLE

any degree of reactivation appears to be possible, even that substantially in excess of original activation, independent of the number of carbon recycles.

d. Coal Pyrolysis Activation

A potential source of makeup carbon and energy is through the addition of coal. Pulverized coal could be added to the carbon-sewage sludge fed to the calciner. Samples of lignite, bituminous and sub-bituminous coal were obtained from Zap, North Dakota, Hillsboro, Illinois and Decker Standard, Montana, respectively. Analysis of the coal on a dry basis for volatile matter, fixed carbon and ash are indicated, Table 6. Ash is relatively low, 5.66 to 12.24%. Moisture on an as received basis, is from 10 to 22%.

Laboratory scale pyrolysis and activation tests were conducted in the one-inch diameter quartz tube and muffle furnace. Pyrolysis and activation conditions were set at 850°C, 20-45 minutes and steam rates of 0.6 to 1.3 grams/min. Coal charge was 11.5-12 grams in the quartz tube. Conditions were similar to those used for pyrolysis and activation of carbon-sewage. Pyrolysis and activation results for lignite, bituminous and sub-bituminous coal are indicated, Table 6. Lignite appeared to be more readily activated than either sub-bituminous or bituminous coal in the preliminary tests. Lignite carbon activation was from 233 to 1154 mg/gram for iodine absorption. The higher activation reflected longer activation times. Pyrolysis and activation of lignite in conjunction with sewage (50%) or $Na_2CO_3$ (5%) appeared to be beneficial for activation relative to activation of lignite without additives, Table 6. The yield of carbon from lignite (dried basis) was from 14 to 34%. The lower yields generally represented very high activation. Carbon ash values after activation were from 22 to 70 wt % with the higher ash representing high activation. Comparison was made of lignite carbon with Aqua Nuchar in sewage treatment. Lignite carbon derived from a blend of lignite and sewage (50%) and lignite with $Na_2CO_3$ (5%) gave equal or better results than Aqua Nuchar in sewage treatment as measured by residual COD, Table 6.

B. PILOT TEST EQUIPMENT

Pyrolysis and activation tests were conducted in pilot test equipment including direct fired rotary kiln, indirected-fired rotary calciners and multiple-hearth reactor, Table 7. Initial testing was conducted at Versa-Tech, Louisville, Kentucky in a 6-1/2-inch I.D. by 7-foot long by 3-foot electrically

Table 6. Coal Pyrolysis and Activation (1-inch Diameter Quartz Tube, Muffle Furnace)

| RUN | MATERIAL | TEMPERATURE (°C) | TIME (min.) | STEAM (g/min) | ACTIVATED CARBON ASH (wt %) | YIELD (%) | AbS. (mg/gram CARBON) | C O D[3] (mg/ℓ) |
|---|---|---|---|---|---|---|---|---|
| 81 | LIGNITE COAL[4] | 850 | 20 | 0.6 | 21.8 | 27.0 | 345 | |
| 78 | LIGNITE COAL[4] | 850 | 20 | 0.6 | 23.0 | 34.0 | 499 | |
| 84 | LIGNITE COAL[4] | 850 | 20 | 1.3 | 30.0 | 22.0 | 589 | |
| 81,83 | LIGNITE COAL[4] | 850 | 40 | 0.6 | 60.6 | 15.0 | 1154 | |
| 85 | LIGNITE COAL[4] | 850 | 40 | 1.3 | 69.7 | 5.0 | 233 | |
| 80A,80B | LIGNITE COAL[4] | 850 | 45 | 0.6 | 34.5 | 34.0 | 492 | |
| 82 | LIGNITE COAL[4] | 900 | 20 | 0.6 | 29.7 | 22.8 | 558 | |
| 79 | SUB BITUMINOUS COAL | 850 | 20 | 0.6 | 9 | 37.0 | 281 | |
| 87 | SUB BITUMINOUS COAL | 850 | 40 | 0.6 | 21.0 | 15.0 | 327 | |
| 77 | BITUMINOUS COAL | 850 | 20 | 0.6 | 23.0 | 38.0 | 210 | |
| 86 | BITUMINOUS COAL | 850 | 40 | 0.6 | 25.0 | 36.0 | 425 | |
| 93 | LIGNITE + 50% SEWAGE | 850 | 20 | 0.6 | 61.7 | 14.1 | 684 | 59 (60) |
| 92 | LIGNITE + 5% $Na_2CO_3$ | 850 | 20 | 0.6 | 31.8 | 21.8 | 821 | 50 (60) |
| 90 | LIGNITE | 850 | 20 | 0.6 | 23.6 | 29.6 | 236 | 94 (60) |

1 - CHARGE IN QUARTZ TUBE, < 100 MESH, DRIED, 11.5-12 grams
2 - YIELD = (grams CARBON/gram DRIED LIGNITE) x 100
3 - RESIDUAL COD (RAW COD = 421) AFTER TREATMENT WITH 500 mg/ℓ CARBON (ℓ) AQUA NUCHAR
4 U. S. BUREAU OF MINES REPORT - VOL. MATTER 42.27%, FIXED CARBON 47.86% ASH 9.87%
5 - U. S. BUREAU OF MINES REPORT - VOL. MATTER 40.84%, FIXED CARBON 53.50% ASH 5.66%
6 - U. S. BUREAU OF MINES REPORT - VOL. MATTER 40.34%, FIXED CARBON 47.42% ASH 12.24%

Table 7. Pyrolysis and Activation ACTS Carbon-Sewage in Pilot Test Equipment

| EQUIPMENT | CARBON-SEWAGE REACTOR FEED | CONDITIONS | RESULTS CARBON<br>ACTIVITY IODINE (mg/g) | YIELD[2] % |
|---|---|---|---|---|
| 6 1/2 in. I.D. x 7 ft LONG,<br>3 ft ELECTRICALLY HEATED ROTARY CALCINER,<br>VERSA TECH,<br>LOUISVILLE, KY | CARBON[1] SEWAGE, 1.2, 1.3<br>MOISTURE - 31, 48%<br>5.7 - 9.7 lbs/hr | 5 RUNS, 1-3 hrs/RUN<br>SOLIDS RETENTION, 9-14 min<br>WALL TEMP. - 800, 860°C<br>GAS TEMP. 650, 760°C<br>STEAM, 0-0.4 lbs/hr<br>NITROGEN, 1-4 $ft^3$/hr | 288-367 | 98-127 |
| 6 1/2 in I.D. x 11 ft LONG,<br>6 ft NATURAL GAS HEATED ROTARY CALCINER, COMBUSTION ENGINEERING, SPRINGFIELD, OHIO | CARBON[1]/SEWAGE, 0.6-1.8<br>MOISTURE - 73%<br>8-10 lbs/hr | 50 hrs OPERATION<br>SOLIDS RETENTION, 10-20 min<br>SOLIDS TEMP., 600-900°C<br>STEAM, 0-1.3 lbs/hr<br>NITROGEN, 1-10 $ft^3$/hr | 330-590 | 65-125 |
| 15 in. I.D. x 12 ft LONG,<br>NATURAL GAS-FIRED ROTARY KILN, COMBUSTION ENGINEERING, SPRINGFIELD, OHIO | CARBON[1]/SEWAGE, ~ 1.0<br>MOISTURE - 73%<br>30 lbs/hr | 2 hr OPERATION<br>SOLIDS RETENTION ~ 10 min<br>TEMP., 850°C | NEGATIVE RESULTS FROM AIR LEAKS AND LARGE VENT LOSSES | |
| 36 in. I.D. x 6 HEARTH FURANCE WITH 2 1/2 HEARTHS IN PLACE, DIRECT NATURAL GAS FIRED.<br>NICHOLS ENG. & RES. CO.,<br>BELLMEAD, N.J. | CARBON[1]/SEWAGE, 0.5-2.0<br>MOISTURE, 58-72%<br>75 lbs/hr, 5000 lb/TOTAL | 66 hr OPERATION<br>SOLIDS RETENTION ~ 30 min<br>GAS TEMP., 840-950°C<br>STEAM - 0 lbs/hr | 350-600 | 70-126 |

1 - DARCO G-60 (IODINE AbS. = 464 mg/gram)
2 - % YIELD = (CARBON OUT/CARBON IN) x 100

heated rotary calciner. Feed rates were at 5.7 to 9.7 lbs/hr of wet (31-48% moisture) carbon-sewage with a retention time of 9 to 14 minutes at wall temperatures of 800-860°C and corresponding gas temperatures of 650-760°C. Steam activation was low because of operational problems with the amount and temperature of steam injected. Operating times were short at 1 to 3 hours because of powdered carbon carryover into the condenser system for the exhaust gases. A small layer of powdered carbon built up in the 1/4-inch condenser tubes and resulted in a gradual calciner pressure buildup to 20-30 inches of water column. Normal operation calls for a maximum pressure of 2-inches of water column. High pressure buildup required reactor shut down, cleanout of condenser tubing, etc. Despite the mechanical problems of operation, carbon-sewage sludge was pyrolyzed and activated. Activation was low, iodine absorption at 288 to 367 mg/gram carbon. The low activation was accompanied by a corresponding high yield of carbon, 98 to 127% based on the activated carbon feed.

Later tests were conducted at the Combustion Engineering test facility at Springfield, Ohio. An uninterrupted 50-hour test was conducted on a 6-1/2-inch I.D. by 11-foot long, 6-foot natural gas fired rotary calciner. Feed rates were 8 to 10 lbs/hr with a very wet (73% moisture) carbon-sewage. Temperatures were varied from 600 to 900°C, solids retention time from 10 to 20 minutes and steam rates from 0 to 1.3 lbs/hour. The resulting carbon activation was iodine absorption of 330-590 mg/gram carbon. Yields were from 65 to 125% based on activated carbon feed. Hourly samples were taken of product carbon and analyzed for iodine absorption and ash content. Product discharge was segregated and weighed on an hourly basis. Very close monitoring of the operation was achieved. Initial operation wasat 600°C and than increased by 100°C increments. It was readily evident that temperatures below 800°C were inadequate for pyrolysis and activation. The product carbon especially at the lower temperatures of 600 and 700°C retained some of the sewage odor and showed very low activation. Test results in the region of 800 to 900°C were very promising for obtaining good pyrolysis and activation. At 15-minutes retention time and 830-850°C, there appeared to be a threshold condition for carbon activation. A temperature of 850°C indicated significantly higher activation and lower yields than operation at 830°C. A very clear tradeoff of yield and activation was evident between 830 and 850°C. Increased retention

time (20 minutes) at 830°C was found to increase the extent of activation but not as greatly as a temperature increase from 830 to 850°C.

A short-duration test was attempted in a 15-inch diameter by 12-foot long natural gas, direct-fired rotary kiln. Feed was 30 lbs/hr for a 10-minute retention time at 850°C. The kiln was far from air tight with relatively large openings in the seals and ends of the calciner. The air leaks resulted in considerable burning of the carbon. Some large (1-2-inch diameter) balls of wet carbon-sewage sludge would tumble down the calciner length. The larger masses of sludge would result in a ash layer on the outside while still maintaining a wet sludge interior. Finer particles of carbon-sewage would be burned entirely or would be carried by the burner gases into the exhaust stack. Although the test was a failure, it did emphasize negative aspects of the direct-fired rotary kiln for carbon-sewage pyrolysis and activation.

Approximately 5000 pounds of wet carbon-sewage sludge (58-72% moisture) was used for 66 hours of operation of a multiple-hearth reactor at Nichols Engineering and Research Company, Belle Mead, New Jersey. Tests were conducted in a 36-inch I. D. by 6 hearth reactor with the top 3-1/2 hearths removed. This change allowed operation at a feed rate of 75 lbs/hour. The incoming feed dropped to the No. 4 hearth (from the top) and slid gently on to the No. 5 hearth. No. 4 hearth constituted only a half-hearth and served the purpose of breaking the fall of the incoming feed. Several bricks were placed on this hearth to slide the feed to the next hearth. Startup of the multiple-hearth was accomplished with 16 mesh sand, followed by feeding local Somerville, New Jersey digested sewage sludge (75% moisture). This startup procedure served to conserve the carbon-sewage feed for steady state operation of the multiple-hearth. A dry cyclone on the exhaust gases provided a capture of powdered carbon leaving the multiple hearth with the exhaust gases. This was followed by a water scrubber and afterburner. Operation of the multiple hearth was carried out with the afterburner both "on" and "off". Approximately 5 to 20% of the product carbon was recovered in the dry cyclone and wet scrubber as carryover from the multiple hearth by the exhaust gases.

A noteworthy observation was that the operation of the multiple-hearth reactor with 100% sewage provided a penetrating sewage odor throughout the vicinity of the pilot plant even with the "afterburner" turned on. Changeover to

a carbon-sewage feed eliminated this widespread sewage odor even with the afterburner turned "off". The presence of carbon with the sewage has a substantial affect in diminishing sewage odors.

Initial operation of the multiple-hearth was conducted at a combustion gas temperature of 950°C with the bed temperature 100°C lower. Under these conditions, activation of the carbon was high, Iodine absorption greater than 1000 mg/gram carbon, but with low yields, 70% or less, yield based on activated carbon feed. To improve carbon yield, gas temperatures were reduced to 840°C. Carbon activation was accordingly reduced, Iodine absorption of 350 mg/gram carbon and yields increased up to 126% (activated carbon feed). The combination of feed rate and rabble arm rotation at 1 R. P. M. provided approximately 30 minutes solids retention in the multiple hearth. Care was exercised to maintain the multiple hearth at a slightly positive pressure to eliminate air leaks. Burners were kept slightly fuel rich (up to 10% excess fuel) to maintain a reducing flame. With these provisions, the test results of carbon activation and yield from the multiple-hearth reactor corresponded to that obtained in the rotary calciner. Since the combustion gases firing the multiple hearth contained approximately 20% moisture, no need was found for separate steam injection. Achieving carbon activation was not a problem with proper activation temperatures.

## C. PYROLYSIS AND ACTIVATION OFF-GAS

Gas samples of off-gas were obtained from the gas holder at Versa-Tech in the operation of the electrically heated rotary calciner and also from the off-gas line of the gas-fired rotary calciner at Combustion Engineerings test facility. The gas analyses are presented on a dry and nitrogen free basis, Table 8. The more complete analyses indicate a high hydrogen content, 30-44 wt %, methane at 10 to 17 wt %, carbon monoxide at 17 to 21 wt %, carbon dioxide at 17 to 21 wt %, ethylene at 3 wt % and ethane at 0.2%. Trace quantities of oxygen (0.2-1.1 wt %) were present but this may constitute leakage of air into the samples. The energy value of this gas is approximately 300 Btu/$ft^3$.

Table 8. Gas Chromatograph Analysis of Carbon-Sewage Pyrolysis and Activation Off Gas

| OFF GASES* (VOL %) | TEST DATE** | | | | | |
|---|---|---|---|---|---|---|
| | 1-1/20/75 | 2-1/20/75 | 3-1/21/75 | 4-1/22/75 | 5-1/23/75 | 4/29/75 (0540) |
| $CO_2$ | — | 17.5 | 19.1 | 17.0 | 18.2 | 21.1 |
| $H_2$ | 11.9 | 30.9 | 34.6 | 41.6 | 38.7 | 44.2 |
| $O_2$ | 0.2 | 0.2 | 0.2 | 0.2 | 0.4 | 1.1 |
| $CH_4$ | 13.05 | 16.7 | 13.2 | 11.4 | 11.0 | 10.3 |
| CO | 13.8 | 20.7 | 18.2 | 19.7 | 17.1 | 17.4 |
| $C_2H_6$ | — | 0.2 | — | 0.2 | 0.2 | — |
| $C_2H_4$ | — | — | — | 3.4 | — | 3.3 |
| $C_3H_6$ | — | — | — | — | — | 0.7 |
| TOTAL ACCOUNTING | 38.9 | 87.0 | 86.3 | 93.5 | 85.6 | 98.1 |

* CORRECTED FOR NITROGEN, WATER
** 1/20-23/75, VERSA - TECH RESULTS : 4/29/75, COMBUSTION ENGINEERING TEST RESULTS

## IV. JPL-ACTS SEWAGE TREATMENT

### A. TEST DATA - 10,000 GPD DEMONSTRATION PLANT AT OCSD

The 10,000 GPD Demonstration Plant, Figure 2, was operated on the JPL-ACTS process at OCSD over the time period of July-August, 1974 and January, 1975. Test data are summarized for primary and secondary treatment of OCSD sewage with activated carbon, Table 9. Carbon additions were in the range of 294 to 751 mg/liter with the raw sewage at COD levels 318 to 767 mg/liter. Corresponding BOD's were 160 to 357 mg/liter. Two stages of carbon treatment resulted in a final effluent BOD of 8 to 57 mg/liter. Filtered samples resulted in BOD values of 10 to 38 mg/liter. Suspended solids in the secondary effluent were high at 36 to 100 mg/liter, suggesting the need for improved settling of suspended solids by addition of flocculating agents and/or inclusion of a gravity filter. Ocean discharge standards for OCSD (ref. 2) call for BOD and suspended solids to be limited to 60 mg/liter on a daily average, 45 mg/liter on a 7-day average and 30 mg/liter on a 30-day average.

### B. LABORATORY SEWAGE TREATMENT RESULTS

#### 1. Commercial and Recycled Carbon

Aqua Nuchar, Darco G-60, Darco S-51 and recycled* Darco S-51 were tested in the JPL-ACTS process (2 stage treatment of sewage with activated carbon), Table 10. Despite the variation in carbon activation as measured by Iodine absorption for the commercial carbons, 460 to 850 mg/g, no significant variations are found in the secondary effluent COD's. Variations in the incoming raw sewage characteristics undoubtedly had a more pronounced effect than the individual variations in carbon activation on the secondary effluent in this test comparison. There are examples of individual instances wherein one or the other activated carbon was found to be more effective in BOD or COD reduction; but, the given treatment advantage does not always persist with changes in incoming sewage. A direct comparison of recycled Darco S-51 that had been reactivated up to three times indicated sewage treatment performance comparable to fresh Aqua Nuchar. Darco S-51 activation after

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* recycled - Darco S-51 that has been processed through the JPL-ACTS Sewage treatment cycle.

Table 9. JPL-ACTS Sewage Treatment Results - 10,000 GPD Demonstration Plant at OCSD

| OCSD SEWAGE INFLUENT | | | | PRIMARY TREATMENT | | | | SECONDARY TREATMENT | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| DATE | S S (mg/ℓ) | C O D (mg/ℓ) | B O D (mg/ℓ) | CARBON ADDED (mg/ℓ) | S S (mg/ℓ) | C O D (mg/ℓ) | B O D (mg/ℓ) | CARBON ADDED (mg/ℓ) | S S (mg/ℓ) | C O D (mg/ℓ) | B O D (mg/ℓ) |
| 7/14/74-8/26/74 | 394-552 | 218-767 | 162-226 | 492-701[1] | 110-238 | 92-303 | 41- | 341-605 | 50-100 | 35-139 | 8-57 |
| 1/6/75 - 1/15/75 | 156-502 | 420-709 | 160-357 | 294-751[2] | 56-120 | 161-243 | 72-110 | 294-751 | 36-94 | 89-228 | 27-56 |
| 1/6/75-1/15/75[3] | — | 123-186 | 46-84 | 294-751[2] | — | 60-145 | 41-75 | 294-751 | — | 47-87 | 10-38 |

1-AQUA NUCHAR AND/OR DARCO G-60
2-DARCO G-60
3-ANALYSES OF FILTERED SAMPLES

Table 10. JPL-ACTS Sewage Treatment Results - Commercial Carbons and Recycle Carbons - Laboratory Determination of COD Reduction

| DATE | CARBON TYPE | CARBON ACTIVATION | ASH (wt %) | IODINE ABS. (mg/ℓ) | SEWAGE INFLUENT COD (mg/ℓ) | PRIMARY TREATMENT CARBON (mg/ℓ) | PRIMARY TREATMENT COD (mg/ℓ) | SECONDARY TREATMENT CARBON (mg/ℓ) | SECONDARY TREATMENT COD (mg/ℓ) |
|---|---|---|---|---|---|---|---|---|---|
| 2/3-25/75 | AQUA NUCHAR | COMMERCIAL | 3 | 850 | 491-646 | 250<br>500<br>1000 | 88-238<br>63-267<br>32-195 | 250<br>500<br>1000 | 56-112<br>32- 93<br>14-47 |
| 2/3-11/75 | DARCO G-60 | COMMERCIAL | 3 | 460 | 517-664 | 250<br>500<br>1000 | 147-251<br>112-201<br>80 | 250<br>500<br>1000 | 67-89<br>112<br>— |
| | DARCO S-51 | COMMERCIAL | 17.5 | 703 | 653 | 400-500 | 57-63 | 400-500 | 54-81 |
| | DARCO S-51 | RECYCLE 1* | 26.5 | 752 | 628 | 500 | 1[illegible]2 | 501 | 71 |
| | DARCO S-51 | RECYCLE 2* | 32.9 | — | 628 | 500 | 120 | 769 | 66 |
| | DARCO S-51 | RECYCLE 3* | 44.0 | 750 | 628 | 500 | 134 | 500 | 90 |
| | AQUA NUCHAR | COMMERCIAL | 3 | 850 | 628 | 695 | 119 | 500 | 70 |

three recycles (750 mg/g) was greater than that of freshly obtained Darco S-51 (703 mg/g). Reactivation of the Darco S-51 was at 850°C for 20 minutes at a steam rate of 0.66 grams/minute over a 10 to 15 gram carbon-sewage charge.

2. Springfield Carbon

Carbon obtained for pyrolysis and activation of carbon-sewage feed in the Combustion Engineering rotary calciner at Springfield, Ohio, was tested in sewage treatment, Table 11. The carbon was the product of calciner operation under low activation, high yield conditions. The Iodine absorption was 277 mg/gram, indicating relatively low activity compared to fresh Darco G-60 at 460 mg/gram. Test results for two stage treatment of OCSD sewage (raw COD-710 mg/l, BOD-244 mg/l) at 300, 500 and 700 mg/l of Aqua Nuchar, Darco G-60 and Springfield carbon are indicated, Table 10. Springfield Carbon despite the low Iodine activity showed sewage treatment results closely comparable to Aqua Nuchar and Darco G-60. At concentrations of 500 and 700 mg/l of carbon addition, the 30-day BOD standards for ocean discharge were met.

3. Evaluation of Sewage Carbon

Sewage Carbon that was prepared by pyrolysis and activation at 750°C with steam activation at 0.207 gram/min for 20 minutes over a 10-15 gram charge of dried sewage, was used in two stage laboratory-scale treatment of OCSD sewage. The sewage carbon was 77.5% ash with an Iodine absorption of 701 mg/g carbon. The test results for sewage treatment are listed, Table 12. Char dosages (carbon and ash) tested were 250, 500, 1000, 2000 and 4000 mg/liter. Raw sewage COD's were from 478 to 694 mg/liter and measured BOD's from 221 to 306 mg/liters. Three of the five sewage samples tested provided BOD's of 7 to 31 mg/liter after a 2 stage char treatment. The remaining two sewage samples afforded BOD's of 38 to 66 when treated twice with char concentrations of 250 to 1000 mg/l (carbon of 56-225 mg/l). The tests demonstrated both the effectiveness of sewage carbon in two-stage carbon treatment and the very significant effects of sewage variations on carbon treatment results.

4. ACTS Treatment with $FeCl_3$

The need for supplementary means to assist meeting suspended solids and BOD standards for OCSD ocean discharge standards with the ACTS process prompted testing with $FeCl_3$ as an adjunct to carbon treatment. Test results

Table 11. Comparison of Springfield* Carbon with Aqua Nuchar and Darco G-60 in ACTS

**(OCSD SEWAGE, RAW COD-710 mg/l, BOD-244 mg/l, FILTERED COD-144 mg/l, BOD-55 mg/l)**

| | | | PRIMARY TREATMENT | | SECONDARY TREATMENT | | |
|---|---|---|---|---|---|---|---|
| CARBON | ASH (wt %) | IODINE ABS. (mg/ℓ) | CARBON (mg/ℓ) | COD (mg/ℓ) | CARBON (mg/ℓ) | COD (mg/ℓ) | BOD (mg/ℓ) |
| AQUA NUCHAR | 3.1 | 1100 | 300 | 90 | 300 | 51 | 22 |
| DARCO G-60 | 3.0 | 465 | 300 | 101 | 300 | 105 | 47 |
| SPRINGFIELD | 21.8 | 277 | 300 | 80 | 300 | 53 | 37 |
| AQUA NUCHAR | 3.1 | 1100 | 500 | 83 | 500 | 35 | 23 |
| DARCO G-60 | 3.0 | 465 | 500 | 92 | 500 | 39 | 19 |
| SPRINGFIELD | 21.8 | 277 | 500 | 56 | 500 | 39 | 29 |
| AQUA NUCHAR | 3.1 | 1100 | 700 | 59 | 700 | 30 | 18 |
| DARCO G-60 | 3.0 | 465 | 700 | 72 | 700 | 29 | 22 |
| SPRINGFIELD | 21.8 | 277 | 700 | 53 | 700 | 47 | 24 |

*CARBON SAMPLE OBTAINED FROM RUN No. 4 4/30/75, TIME 2400-0100 OF PYROLYSIS-ACTIVATION OF DARCO G-60-SEWAGE IN ROTARY CALCINER AT COMBUSTION ENGINEERING TEST FACILITY IN SPRINGFIELD, OHIO

Table 12. Evaluation of Sewage Carbon for ACTS Process (Sludge Carbon Pyrolyzed and Activated at 750°C for 20 min with 0.207 g/min Steam, Ash = 77.5 wt %, Iodine Absorption-701 mg/gram Carbon)

| OCSD SEWAGE | | | | PRIMARY TREATMENT | | | SECONDARY TREATMENT | | |
|---|---|---|---|---|---|---|---|---|---|
| RAW | | FILTERED | | | | | | | |
| COD (mg/ℓ) | BOD (mg/ℓ) | COD (mg/ℓ) | BOD (mg/ℓ) | CHAR DOSAGE (mg/ℓ) | COD (mg/ℓ) | BOD (mg/ℓ) | CHAR DOSAGE (mg/ℓ) | COD (mg/ℓ) | BOD (mg/ℓ) |
| 35 | 223 | 155 | — | 250 | 134 | 29 | 250 | 105 | 31 |
| | | | | 500 | 115 | 39 | 500 | 83 | 21 |
| | | | | 1000 | 92 | 34 | 1000 | 57 | 27 |
| 512 | 306 | 150 | — | 250 | 162 | 84 | 250 | 105 | 51 |
| | | | | 500 | 122 | 68 | 500 | 83 | 47 |
| | | | | 1000 | 105 | 66 | 1000 | 71 | 38 |
| 557 | — | 143 | — | 500 | 122 | 54 | 500 | 110 | 36 |
| | | | | 1000 | 102 | 38 | 1000 | 91 | 29 |
| | | | | 2000 | 85 | 34 | 2000 | 67 | 12 |
| | | | | 2000 | 78 | — | 2000 | 45 | — |
| 478 | 221 | 108 | 43 | 500 | — | 71 | 500 | 98 | 26 |
| | | | | 1000 | — | 19 | 1000 | 82 | 22 |
| | | | | 2000 | — | 33 | 2000 | 60 | 23 |
| | | | | 4000 | — | — | 4000 | 52 | 7 |
| 694 | — | 181 | 102 | 500 | 213 | 74 | 500 | — | 64 |
| | | | | 1000 | — | 71 | 1000 | 156 | 66 |
| | | | | 2000 | 169 | — | 2000 | 129 | — |

are included, Table 13. $FeCl_3$ concentrations from 20 to 100 mg/liter in secondary treatment were tested in conjunction with Aqua Nuchar two stage treatment from 250 to 1000 mg/liter. The effects on COD reduction of $FeCl_3$ additions were sometimes very pronounced and in other instances showed little gain. The efficacy of $FeCl_3$ addition to carbon treatment is evidently highly dependent on sewage characteristics. Since $FeCl_3$ serves as an effective settling aid (see Settling Column test results), the use of $FeCl_3$ can be justifed solely on the reduction of suspended solids and attendant BOD.

## C. METALS TREATMENT

Test results were obtained on the 10,000 GPD JPL-ACTS demonstration plant at OCSD from June through August, 1974 for metals removal. The test results are listed, Table 14. The metals monitored included those covered by the pending ocean discharge standards for OCSD (ref. 2). Arsenic which is not included in the metals tabulated but is included in the standards meets the standards for ocean discharge along with mercury without treatment. The major problem with metals in the treated sewage is with chromium which exceeds projected daily standards by 7 to 25. Source control may be the only limiting remedy for chromium discharges. Cadmium, copper and nickel were occasionally found to exceed projected daily standards for discharge but not to any excessive extent.

## D. TURBIDITY, GREASE, AND AMMONIA

Test results were obtained on the 10,000 GPD JPL ACTS demonstration plant at OCSD from June through August, 1974. Test results are summarized, Table 15. Turbidity levels were well within the daily maximum standard of 75 mg/l. Grease on occasion, slightly exceeded the daily maximum standard of 15 mg/liter. Ammonia concentrations were unaffected by carbon treatment and exceeded the daily maximum standard of 40 mg/liter. Source control for ammonia will be required to meet discharge standards.

## E. PHENOL AND CYANIDE

Laboratory tests indicated carbon treatment to be very effective in reducing conce[illegible]ations of phenols and cyanides, Table 16. The concentrations after treatment were well below daily maximum standards.

Table 13. ACTS Treatment with $FeCl_3$

| | | PRIMARY TREATMENT | | SECONDARY TREATMENT | | |
|---|---|---|---|---|---|---|
| SAMPLE DATE | RAW SEWAGE COD (mg/ℓ) | AQUA NUCHAR (mg/ℓ) | COD (mg/ℓ) | AQUA NUCHAR (mg/ℓ) | $FeCl_3$ (mg/ℓ) | COD (mg/ℓ) |
| 3/25/75 | 800 | 500 | 229 | 500 | — | 180 |
| | | 500 | 229 | 500 | 100 | 28 |
| 3/31/75 | 576 | 500 | 108 | 500 | — | 51 |
| | 576 | 500 | 108 | 500 | 100 | 37 |
| 4/7/75 | 552 | 500 | 71 | 500 | — | 39 |
| | | 500 | 71 | 500 | 100 | 31 |
| 5/16/75 | 557 | 500 | 71 | 500 | — | 31 |
| | | 500* | 122 | 500* | — | 110 |
| | | 500* | 122 | 500* | 100 | 89 |
| 4/21/75 | 478 | 500 | 58 | 500 | — | 21 |
| | | 500* | — | 500* | — | 98 |
| | | 500* | | 500* | 100 | 60 |
| 4/28/75 | 700 | 250* | — | 250 | — | 110 |
| | | 250* | | 250 | 20 | 96 |
| | | 500 | — | 500 | — | 81 |
| | | 500 | | 500 | 20 | 64 |
| | | 1000* | — | 1000 | — | 57 |
| | | 1000* | | 1000 | 20 | 53 |
| 5/7/75 | 755 | 500 | 85 | 500 | — | 67 |
| | | 500 | 85 | 500 | 25 | 81 |
| | | | | 500 | 50 | 77 |
| | | | | 500 | 75 | 80 |
| | | | | 500 | 100 | 81 |
| 5/5/75 | 593 | 500 | — | 500 | — | 49 |
| | | 500* | — | 500 | — | 51 |
| | | 500* | | 500 | 25 | 42 |
| | | 500* | | 500 | 50 | 56 |
| | | 500* | | 500 | 75 | 43 |
| | | | | 500 | 100 | 47 |

*SEWAGE CARBON: ~ 77 wt. % ASH

ORIGINAL PAGE IS OF POOR QUALITY

Table 14. Metals Treatment 10,000 GPD JPL ACTS Demonstration Plant at OCSD

TEST PERIOD: 6/7/74 - 8/20/74

| METALS | SEWAGE INFLUENT (mg/ℓ) | PRIMARY EFFLUENT (mg/ℓ) | SECONDARY EFFLUENT (mg/ℓ) | STANDARD (DAILY MAX.) (mg/ℓ) |
|---|---|---|---|---|
| CADMIUM | 0.024 - 0.25 | 0.02 - 0.08 | 0.02 - 0.04 | 0.03 |
| CHROMIUM | 0.03 - 0.82 | 0.14 - 0.33 | 0.07 - 0.25 | 0.01 |
| COPPER | 0.49 - 4.2 | 0.15 - 1.44 | 0.1 - 0.47 | 0.3 |
| LEAD | 0.11 - 0.46 | 0.03 - 0.2 | 0.02 - 0.16 | 0.2 |
| MERCURY | < 0.002 | — | — | 0.002 |
| NICKEL | 0.11 - 0.52 | 0.1 - 0.36 | 0.06 - 0.33 | 0.2 |
| SILVER | 0.004 - 0.04 | 0.004 - 0.01 | 0.002 - 0.01 | 0.04 |
| ZINC | 0.05 - 1.1 | 0.01 - 0.52 | 0.11 - 0.36 | 0.5 |

Table 15. Turbidity, Grease, Ammonia 10,000 GPD JPL ACTS Demonstration Plant at OCSD

TEST PERIOD: 6/17/74 - 8/20/74

| ANALYSES | SEWAGE INFLUENT (mg/ℓ) | PRIMARY EFFLUENT (mg/ℓ) | SECONDARY EFFLUENT (mg/ℓ) | STANDARD (DAILY MAX.) (mg/ℓ) |
|---|---|---|---|---|
| TURBIDITY | 120 - 350 | 10 - 50 | 10 - 25 | 75 |
| GREASE | 41 - 70 | 2 - 28 | 2 - 16 | 15 |
| AMMONIA | 29 - 70 | 36 - 65 | 42 - 63 | 40 |

Table 16. Phenol and Cyanide, JPL ACTS Process Lab Treatment

| ANALYSES | SEWAGE* INFLUENT (mg/ℓ) | SECONDARY EFFLUENT (mg/ℓ) | STANDARD (DAILY MAX.) (mg/ℓ) |
|---|---|---|---|
| PHENOLS | 0.025 - 0.2 | 0.001 - 0.005 | 1.0 |
| CYANIDE | 1.0 | 0.01 | 0.2 |

*TEST DATES 3/25/75, 4/23/75, 5/28/75

## F. SETTLING COLUMN TESTS

A 6-inch diameter by 10-foot high lucite column with sample taps at 2, 4, 6 and 8 feet from the top of the column was used for settling tests with OCSD sewage treated with 500 mg/liter Hydrodarco C. Tests were conducted with once and twice treated sewage at settling times of 5, 15, 30, 60 and 120 minutes, Table 17. Tests results indicated that turbidity and suspended solids standards were not met with 120 minutes of settling although the secondary treatment provided somewhat improved settling.

Settling column tests were conducted with Aqua Nuchar, 500 mg/l, and the addition of $FeCl_3$ and Purifloc A-23. The first-stage carbon treatment included 40 ppm $FeCl_3$ and 0.5 ppm Purifloc A-23. Second-stage carbon treatment included 10 ppm $FeCl_3$ and 0.25 ppm Purifloc A-23. Test data at 5, 15, 30, 60 and 120 minutes are included for test column samples at 2, 4, 6 and 8 feet from the top, Table 18. Test data for primary treatment settling indicates that turbidity and suspended solids levels meet discharge standards within 30 to 60 minutes settling times.

Secondary treatment settling meets turbidity and suspended solids discharge standards within 15 to 30 minutes settling times, Table 18. Test results indicate the necessity of introducing $FeCl_3$ as an effective settling aid for both the primary and secondary treatment sections. Other laboratory data have indicated that other cationic polymers such as American Cyanamid's 509C at 5 ppm are equally effective but more costly settling aids. More recent laboratory data suggests that the addition of Purifloc A-23 to the $FeCl_3$ may be unnecessary and may be a liability in assisting settling.

## G. GRAVITY (MULTI-MEDIA) FILTERS

Three multi-media filter test columns, 4.5-inch diameter by 4-feet, were obtained from Neptune Microfloc, Inc. The composition of the multi-media tested is listed, Table 19. The initial media tested included a 16 to 24-inch top layer of 1 mm anthracite followed by a 9-inch layer of 0.5 mm silica and a 1.5 to 4.5-inch layer of 0.2 mm garnet. One of the columns was subsequently modified to a dual media consisting of 22-inches of 2 mm low-density coal with 12-inches of 1 mm silica. A second column was modified to incorporate a 9-inch layer of 2 mm low density coal, a 9-inch layer of 1 mm anthracite, a 9-inch layer of 0.5 mm silica and 4.5-inches of 0.2 mm garnet.

Table 17. Settling Column* Test Results (Turbidity (JTU) and Suspended Solids (mg/l))

OCSD SEWAGE TREATED ONCE WITH HYDRODARCO-C (500 mg/ℓ)

| COLUMN SAMPLE FROM TOP (ft) | SETTLING TIMES (minutes) 5 | | 15 | | 30 | | 60 | | 120 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | TURB. (JTU) | S. S. (mg/ℓ) | TURB. (JTU) | S. S (meg/ℓ) | TURB. (JTU) | S. S (mg/ℓ) | TURB. (JTU) | S. S (mg/ℓ) | TURB. (JTU) | S. S (mg/ℓ) |
| 2 | 500+ | 200 | 269 | 140 | 233 | 200 | 211 | 80 | 149 | 70 |
| 4 | 500+ | 470 | 240 | 180 | 211 | 160 | 175 | 140 | 178 | 160 |
| 6 | 500+ | 470 | 211 | 160 | 200 | 160 | 164 | 120 | 160 | 110 |
| 8 | 500+ | 500 | 200 | 120 | 218 | 240 | 185 | 120 | 167 | 170 |

OCSD RAW SEWAGE TREATED TWICE WITH HYDRODARCO-C (500 mg/ℓ)

| COLUMN SAMPLE FROM TOP (ft) | 5 TURB. (JTU) | 5 S. S. (mg/ℓ) | 15 TURB. (JTU) | 15 S. S (meg/ℓ) | 30 TURB. (JTU) | 30 S. S (mg/ℓ) | 60 TURB. (JTU) | 60 S. S (mg/ℓ) | 120 TURB. (JTU) | 120 S. S (mg/ℓ) |
|---|---|---|---|---|---|---|---|---|---|---|
| 2 | 500+ | 440 | 260 | 100 | 200 | 100 | 176 | 40 | 148 | 50 |
| 4 | 500+ | 560 | 260 | 180 | 216 | 160 | 176 | 80 | 150 | 30 |
| 6 | 500+ | 680 | 288 | 160 | 216 | 100 | 188 | 20 | 164 | 80 |
| 8 | 500+ | 650 | 288 | 540 | 236 | — | 188 | — | 168 | 85 |

*6-inch x 10 feet HIGH

Table 18. Settling Column Test Results (Turbidity (JTU) and Suspended Solids (mg /l))

OCSD SEWAGE TREATED <u>ONCE</u> WITH AQUA NUCHAR (500 mg/ℓ)
AND $FeCl_3$ (40 ppm,) PURIFLOC A-23 (0.5 ppm)

SETTLING TIMES (minutes)

| COLUMN* SAMPLE FROM TOP (ft) | 5 | | 15 | | 30 | | 60 | | 120 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | TURB. (JTU) | S.S (mg/ℓ) | TURB. (JTU) | S.S (mg/ℓ) | TURB. (JTU) | S.S (mg/ℓ) | TURB. (JTU) | S.S (mg/ℓ) | TURB. (JTU) | S.S (mg/ℓ) |
| 2 | 108 | 120 | 32 | 48 | 16 | 44 | 17 | 24 | 19 | 16 |
| 4 | 500+ | 560 | 29 | 52 | 21 | 44 | 22 | 20 | 19 | 32 |
| 6 | 500+ | 1040 | 34 | 32 | 23 | 24 | 23 | 13 | 21 | 28 |
| 8 | 500+ | 1220 | 34 | 52 | 22 | 16 | 27 | 16 | 23 | 32 |
| OCSD SEWAGE TREATED <u>TWICE</u> WITH AQUA NUCHAR (500 mg/ℓ) AND $FeCl_3$ (10 ppm), PURIFLOC A-23 (0.25 ppm) | | | | | | | | | | |
| 2 | 500+ | 260 | 40 | 28 | 20 | 20 | 16 | 20 | 12 | 16 |
| 4 | 500+ | 470 | 45 | 28 | 27 | 28 | 17 | 20 | 11 | 16 |
| 6 | 500+ | 1000 | 30 | 24 | 24 | 28 | 16 | 20 | 12 | 16 |
| 8 | 500+ | 980 | 36 | 20 | 23 | 24 | 16 | 20 | 15 | 16 |

*10-foot x 6-inch DIAM. COLUMN

Table 19. Gravity (Multi-Media) Filter Tests (Neptune Microfloc Test Columns) 4.5-inch Diameter x 4-feet

| | GARNET | | SILICA | | ANTHRACITE | | LOW-DENSITY COAL | |
|---|---|---|---|---|---|---|---|---|
| FILTER COLUMN | HEIGHT (in.) | SIZE (mm) | HEIGHT (in.) | SIZE (mm) | HEIGHT (in.) | SIZE (mm) | HEIGHT (in.) | SIZE (mm) |
| 01 | 1.5 | 0.2 | 9 | 0.5 | 24 | 1 | | |
| 02 | 3 | 0.2 | 9 | 0.5 | 22.5 | 1 | | |
| 03 | 4.5 | 0.2 | 9 | 0.5 | 16 | 1 | | |
| A2 | — | — | 12 | 1 | — | — | 22 | 2 |
| A3 | 4.5 | 0.2 | 9 | 0.5 | 9 | 1 | 9 | 2 |

The influent for the multi-media filter tests was obtained by contacting 1000 gallon batches of OCSD sewage and treatment with Aqua Nuchar at 500 mg/liter in a 1000 gallon mix tank equipped with a paddle mixer. A summary of treatment conditions, contact time and settling times for preparation of the sewage influent is listed, Table 20.

A summary of test results on the multi-media test columns is included, Table 21. Run designations refer back to Table 19 for influent designations and to Table 18 for column designations. Contrary to settling column test results, the carbon-sewage suspended solids settled more rapidly than expected. This may be in part the result of increased carbon contact times and/or changes in sewage characteristics. Flow rates tested were 5.4 to 9 gpm/ft$^2$. Run times were from 35 minutes to over 20 hours. Run durations (termination) were dictated by either a buildup of head or by running out of influent. The filter head at the end of the run indicates the reason for run termination. Low head buildup suggests the run was terminated by exhaustion of influent. Maximum head buildup is 16 feet. The test experience indicates that once treated sewage contains some slime in the influent to the gravity filter and rapidly produces a fibrous mat on top of the filter bed, and is responsible for 90% of the head pressure buildup. Tests indicate that turbidity levels were reduced from 60 to 90%, with the effluent at 1 to 32 JTU's. Twice treated sewage overcomes this problem. Use of coarse media provided good bed penetration and acceptable filtration.

Final recommendations for the mixed-media filter in the 1 MGD Pilot Plant are: 24-inches of 1.5-1.6 mm anthracite, 1.5 uniformity; and 12-inches of 0.7-0.8 mm silica sand, 1.5 uniformity. Expected operating conditions for the gravity filter are: flow rates of 7.3 gpm/ft$^2$; backwash flows of 25-30 gpm/ft$^2$; filtration cycle between backwashes - 8 to 24 hours; turbidity reduction of 60 to 80%. The choice of the dual media provides good bed penetration, long filter runs between backwashes, and effective reduction of suspended solids and turbidity to meet standards based on expected influent characteristics to the gravity filter. It may be entirely possible that the gravity filter will not be required for meeting turbidity and suspended solids standards but will be effective in providing some additional polishing action in BOD reduction that is important.

Table 20. Gravity Filter Tests Influent Description (1000 gallons OCSD Sewage Treated with Aqua Nuchar)

| RUN | PICK-UP | RUN START | CARBON (mg/ℓ) | CONTACT TIME (min) | SETTLING TIME (min) | COMMENT |
|---|---|---|---|---|---|---|
| 1 | 8-20-0700 | 8-20-1315 | 500 | 60 | 60 | POOR CONTACT, SETTLING |
| 2 | 8-20-0700 | 8-21-1045 | 500/500 | 60/60 | 60/60 | VERY GOOD SETTLING |
| 3 | 8-25-0700 | 8-25-1300 | 500 | 60 | 60 | MIXER BREAK-DOWN |
| 4 | 8-25-0700 | 8-26-0950 | 500/0 | 60/60 | 60/45 | |
| 5 | 8-26-1400 | 8-27-1000 | 500 | 900 | 60 | SLOW MIX OVERNIGHT |
| 6 | 8-26-1400 | 8-27-1200 | 500 | 900 | 60 | |
| 7 | 8-28-0720 | 8-27-1515 | 500/500 | 30/45 | 30/30 | |
| 8 | 9-03-0730 | 9-03-1345 | 500/500 | 45/40 | 30/15 | |
| 9 | 9-08-1115 | 9-09-0915 | 500/500 | 45/30 | 30/15 | INTERMITTENT RUN |
| 10 | 9-15-0800 | 9-15-1445 | 500/500 | 60/30 | 30/30 | VERY GOOD SETTLING |
| 11 | 9-16-1600 | 9-17-0910 | 500/0 | 800/30 | 15/20 | SLOW MIX OVERNIGHT |
| 12 | 9-19-1000 | 9-19-1255 | 500 | 45 | 30 | TAP WATER |

Table 21. Gravity Filter Preliminary Tests Results

| RUN | FILTER | TURBIDITY INFLUENT* (JTU) | TURBIDITY EFFLUENT (JTU) | FLOW RATE (gpm/sq ft) | RUN TIME (hr:min) | FILTER HEAD START (ft) | FILTER HEAD FINISH (ft) |
|---|---|---|---|---|---|---|---|
| 1 | 01, 02, 03 | — | | 9 | 1:50 | 4.0 (03) | 16.0 |
| 2 | 01, 02, 03 | 12 | 4 | 9 | 3:15 | 4.0 (03) | 4.5 |
| 3 | 01, 02, 03 | 220 | 25 | 9 | 0:35 | 4.0 (03) | 8.2 |
| 4 | 01, 02, 03 | 86 | 13 | 6.7 | 5:10 | 2.8 (03) | 7.0 |
| 5 | 01, 02, 03 | 64 | 17 | 6.7 | 1:50 | 2.6 (03) | 10.5 |
| 6 | 01, 02, 03 | 71 | 14 | 5.4 | 2:10 | 1.6 (03) | 9.5 |
| 7 | 03 | 25 | 5 | 6.7 | 19:40 | 2.6 | 8.5 |
| 8 | 03 | 14 | 1 | 6.7 | 20:45 | 2.5 | 4.5 |
| 9 | 03 | 48 | 14 | 6.7 | 4:00 | 2.6 | 10+ |
| 10 | 01 | 5 | 2 | 9 | 5:30 | 3.0 | 4.5 |
| 10 | A2 | 5 | 2 | 9 | 5:30 | 0.8 | 1.0 |
| 10 | A3 | 5 | 2 | 9 | 5:30 | 2.9 | 3.7 |
| 11A | A2 | 86 | 32 | 9 | 1:30 | 0.6 | 11.5 |
| 11A | A3 | 86 | 19 | 9 | 1:20 | 2.9 | 14.0 |
| 11B | 01 | 78 | 17 | 5.4 | 3:00 | 1.8 | 16.0 |
| 11B | A2 | 78 | 24 | 5.4 | 5:50 | 0.4 | 7.0 |
| 11B | A3 | 78 | 17 | 5.4 | 4:00 | 1.6 | 12.0 |
| 12 | 01 | 90 | 6/2 | 9 | 3:00 | 3.3 | 4.2 |
| 12 | A2 | 90 | 26/10 | 9 | 2:20 | 0.7 | 16.5 |
| 12 | A3 | 90 | 6/2 | 9 | 3:30 | 3.4 | 4.0 |

*1000 GALLON BATCHES OCSD SEWAGE TREATED WITH AQUA NUCHAR AT 500 mg/ℓ, CONTACT TIME 30-60 minutes, SETTLING TIME 15-60 minutes, ONE AND TWO CARBON TREATMENTS

## V. ECONOMICS

Capital costs were projected for installation of a 175 MGD plant based on "JPL-ACTS" and "Activated Sludge With Roughing Filters and Incineration." Capital costs for the total treatment plant exclusive of land are in the range of 150-200 million. Preliminary estimates indicate that the JPL-ACTS process provides up to a 25% capital cost savings over competitive sewage treatment in order to meet projected ocean discharge standards.

Operating, Maintenance, Capital Amortization and Interest charges were calculated for a 175 MGD plant based on "JPL-ACTS' and "Activated Sludge with Roughing Filters and Incineration." The JPL-ACTS process showed a competitive cost advantage in Operating and Maintenance costs. Because of the significant capital cost advantages for JPL-ACTS, Capital Amortization and Interest charges for JPL-ACTS showed a substantial savings. Total annual charges for a 175 MGD plant reflect a 20-25% savings for the JPL-ACTS process.

## VI. CONCLUSION

A JPL-ACTS 1 MGD Pilot Plant is currently under construction at OCSD. Operation of the 1 MGD pilot facility will be required to prove the ability of the JPL-ACTS process to meet ocean discharge standards and to confirm the economic advantages of the process. The pilot plant will be operated over a sufficiently long period to reflect daily and seasonal variations in the incoming sewage. To establish performance under these variable conditions will be extremely important for proving the merits of the JPL-ACTS process.

## REFERENCES


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NASA — JPL — Coml., L.A., Calif.